SQUID Multiplexers for Cryogenic Detector Arrays

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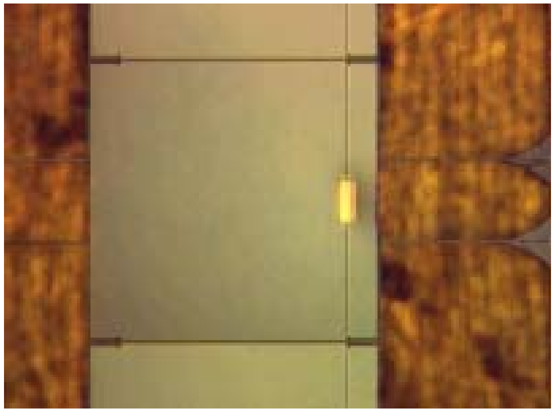
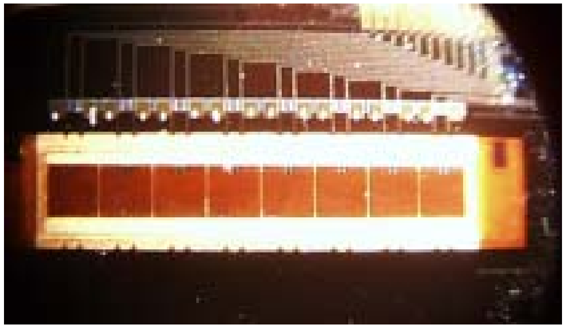
TDW 2003
University of Maryland

Some TES Bolometers fabricated at NIST

"Popup" TES bolometer

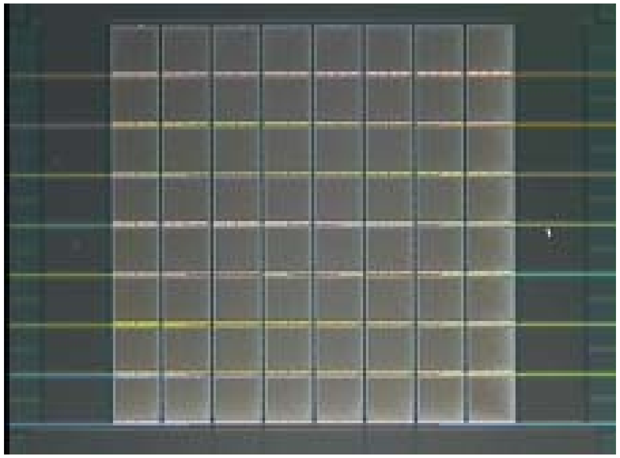


1 × 8 Popup Array

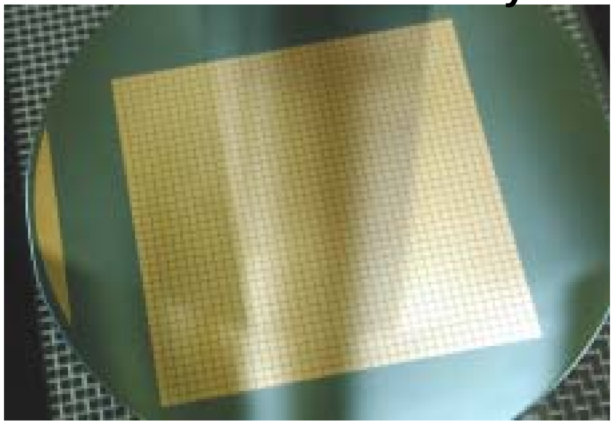


Collaboration with Harvey Moseley, NASA/GSFC

8 × 8 X-Ray Array



32 × 40 SCUBA-2 Array



(SCUBA-2 array not yet micromachined)

Collaboration with SCUBA-2 Consortium

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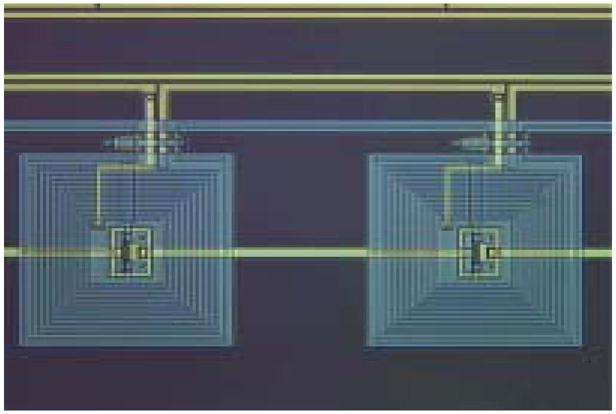
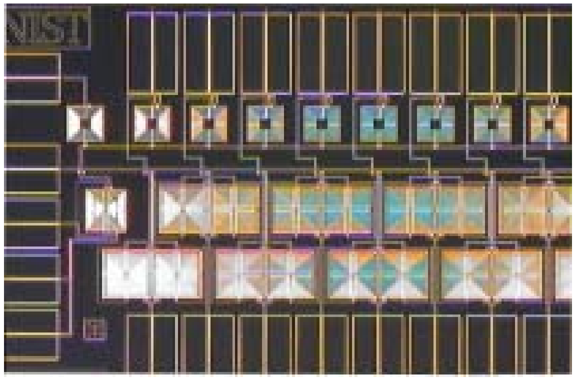
Nb SQUID Processing

- Fabricated at NIST
- Standard $Nb/Al/Al_2O_3/Nb$ trilayer technology
- Robust and rad hard
- Works up to near the Nb transition temperature (9 K)

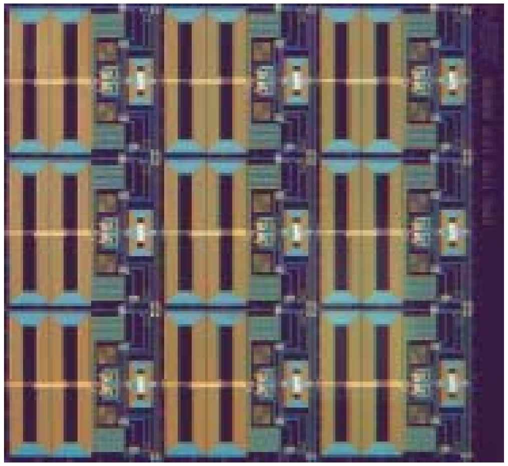
100-SQUID Series Array for the Cryogenic Dark Matter Search



1 × 32 MUX Array for Constellation-X



3 × 3 SCUBA-2 MUX Array



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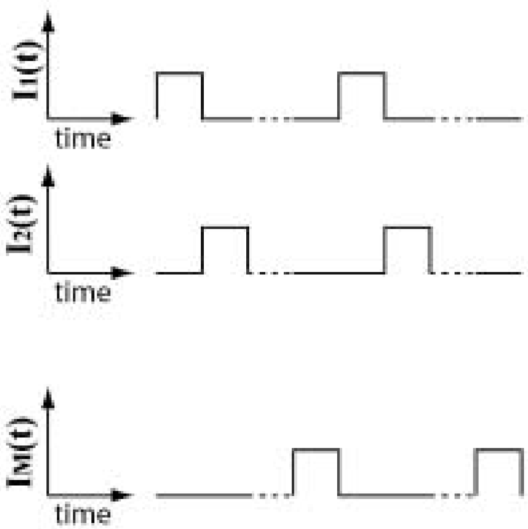
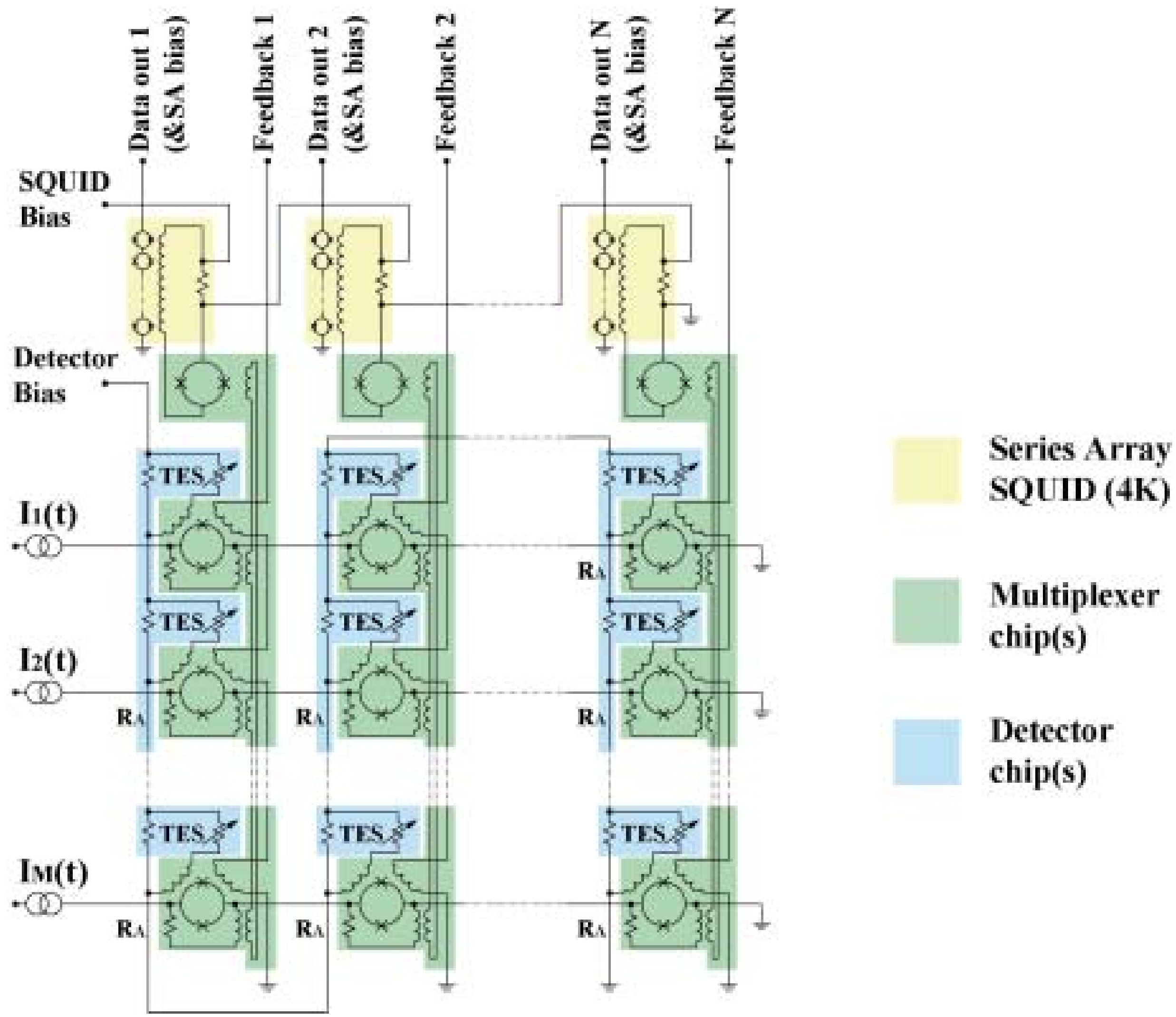
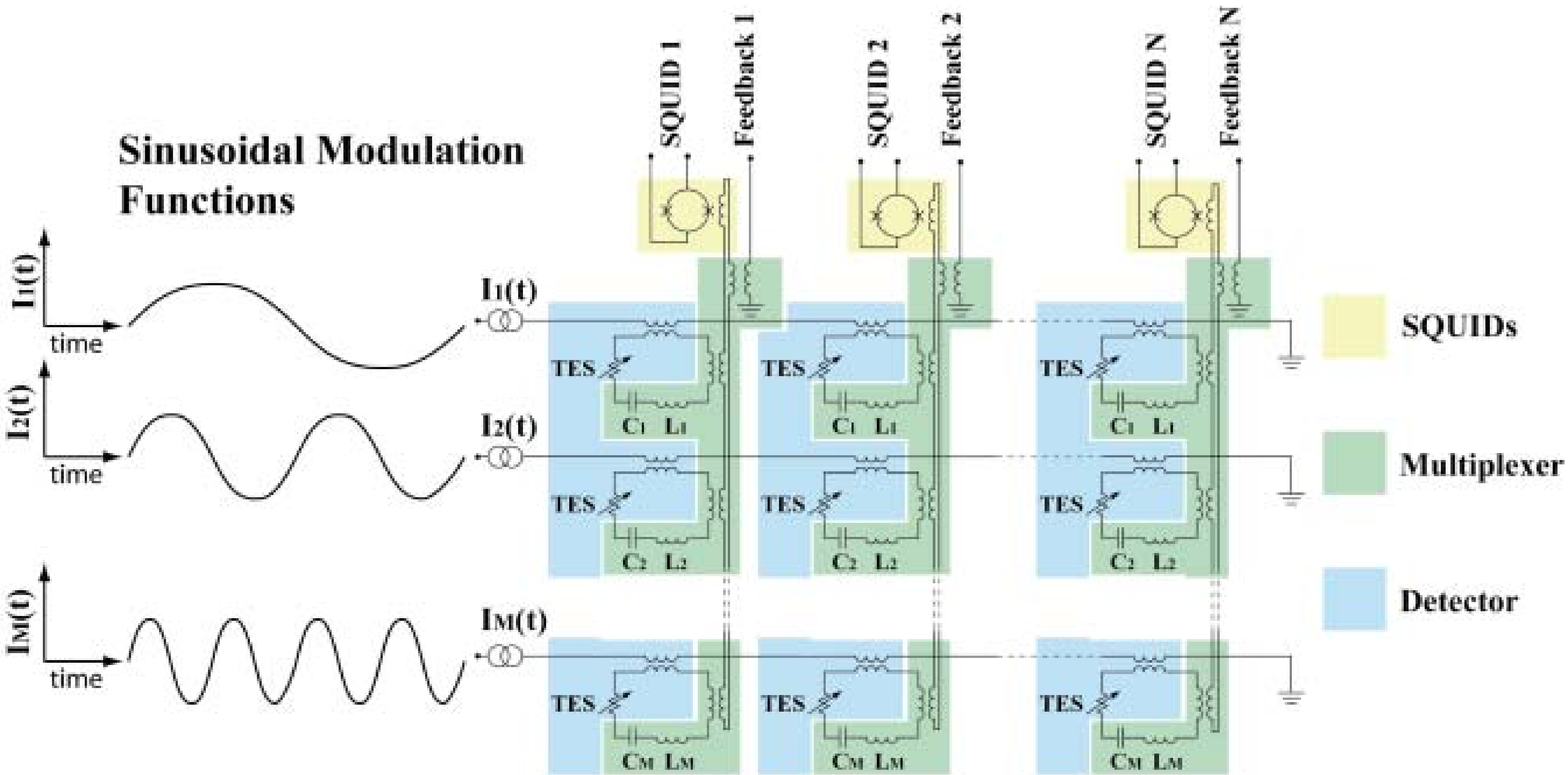
Time-Division SQUID Multiplexer

Boxcar Modulation Functions
(can be from Cryogenic CMOS MUX)





Frequency-Division SQUID Multiplexer



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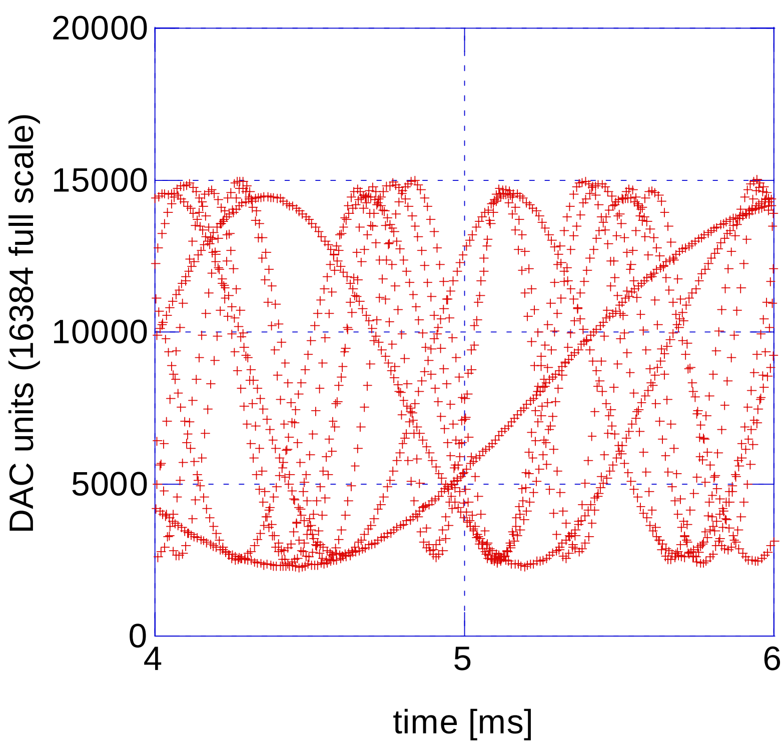
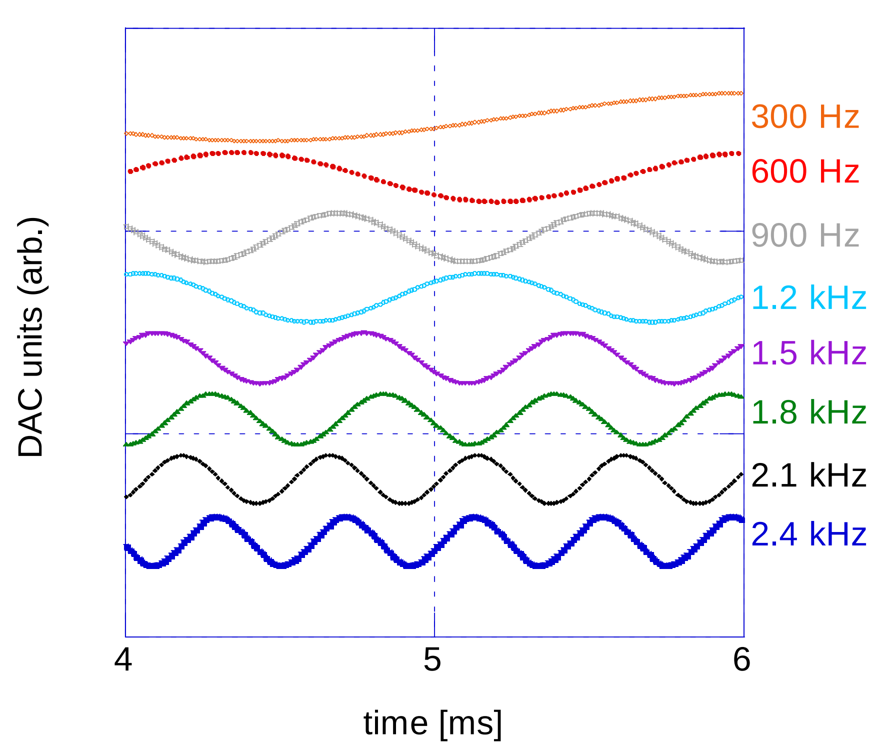
MUX Functionality

- 8 sinusoidal signals to 8 channels of MUX chip in 4 K probe
- Line rate 1.56 MHz





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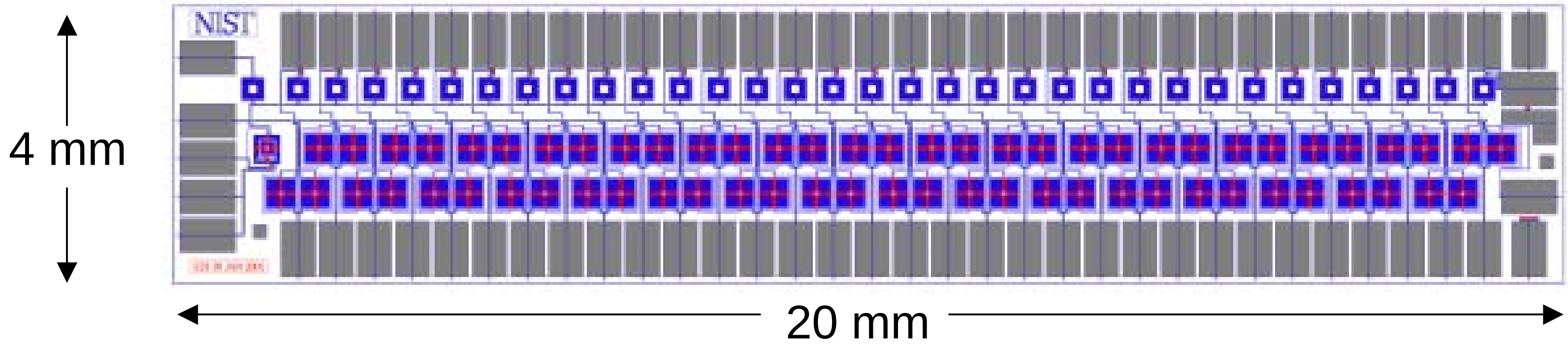
Analog SQUID MUX power

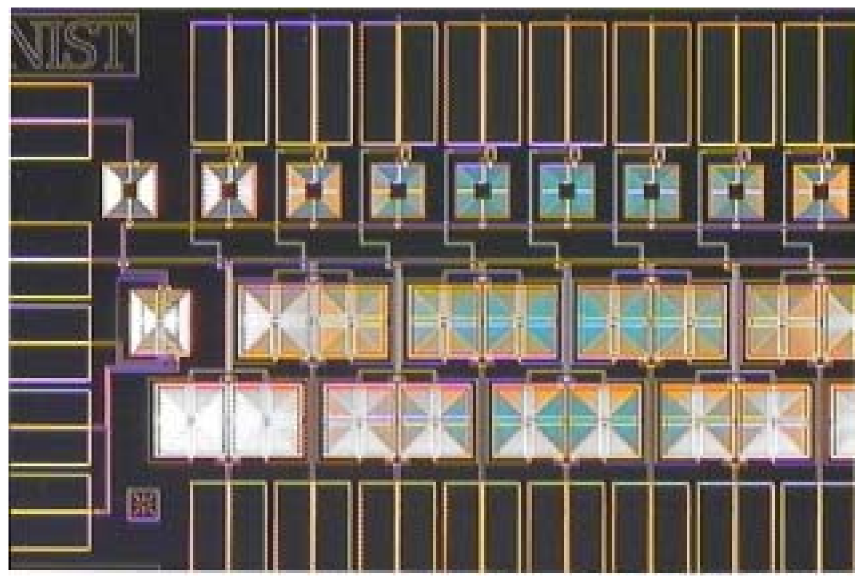
1st stage of amplification
~ 3 nW per column

2nd stage of amplification
(series-array SQUIDs)
~ 300 nW per column

Total power for a 1000-pixel (32×32) array:
~ 100 nW 1st stage
~ 10 μW 2nd stage

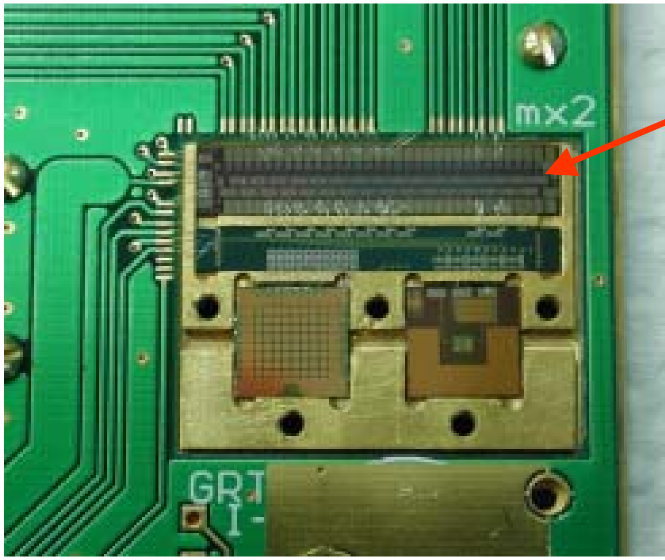
2nd-Generation 32 x N Multiplexer

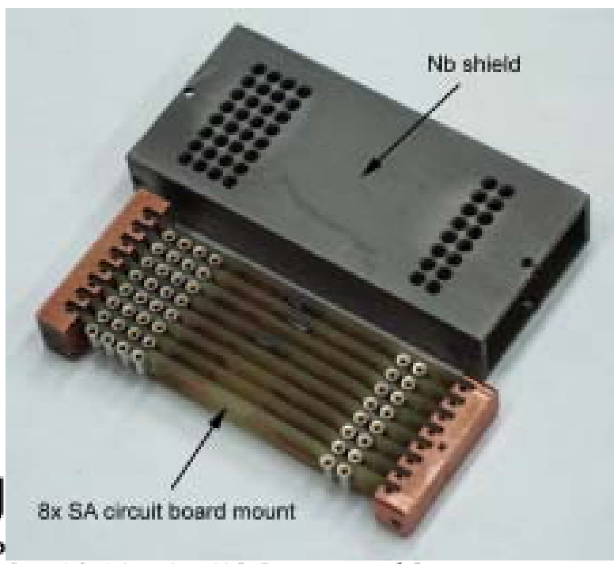


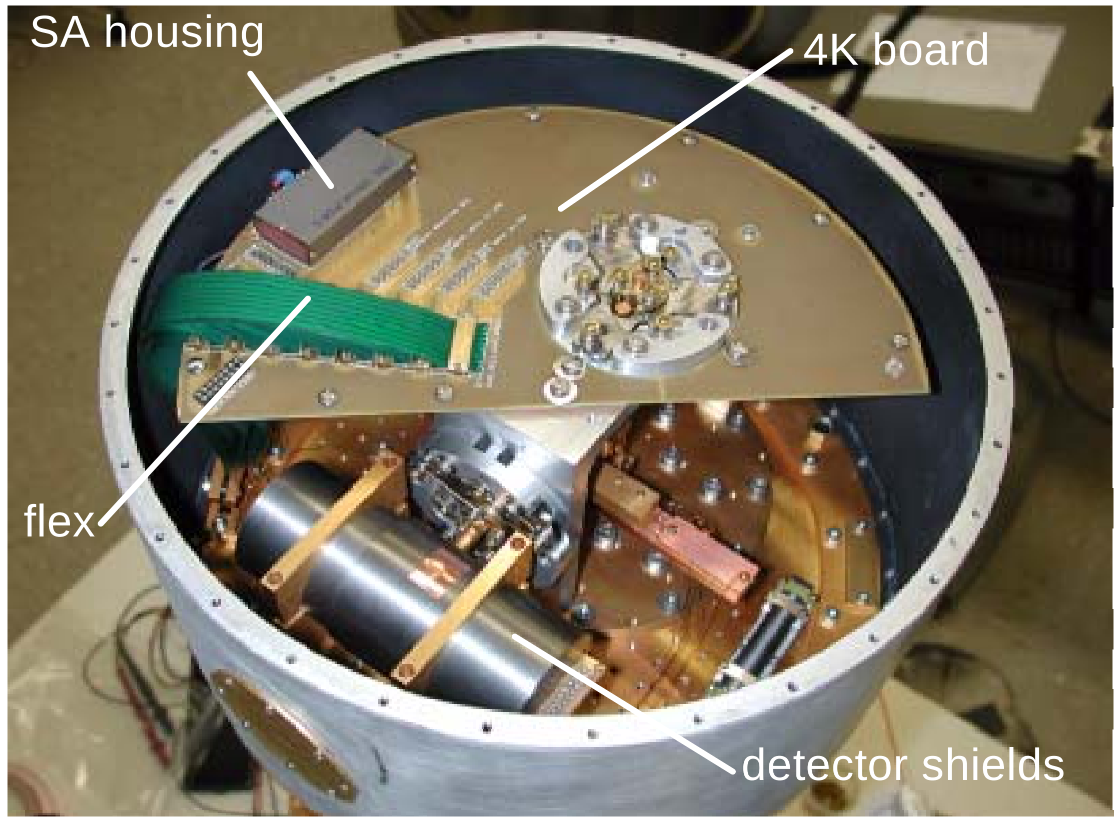


- Need 32 chips to instrument kilopixel array.

0.1 K ADR Test Facility

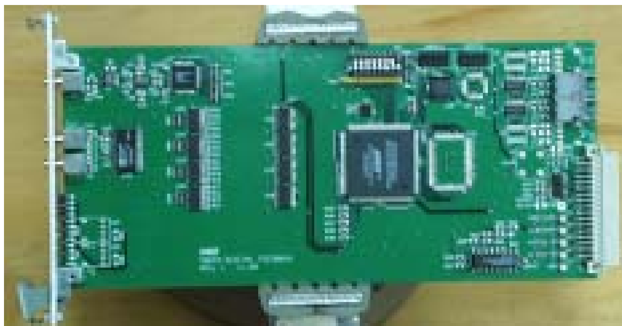




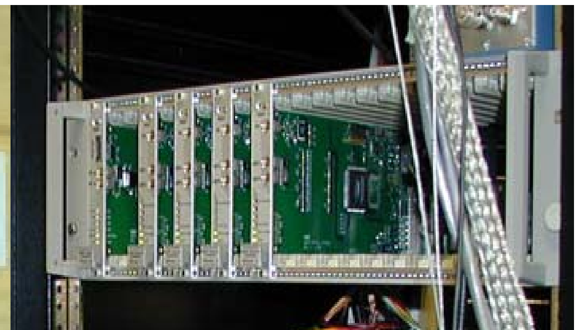


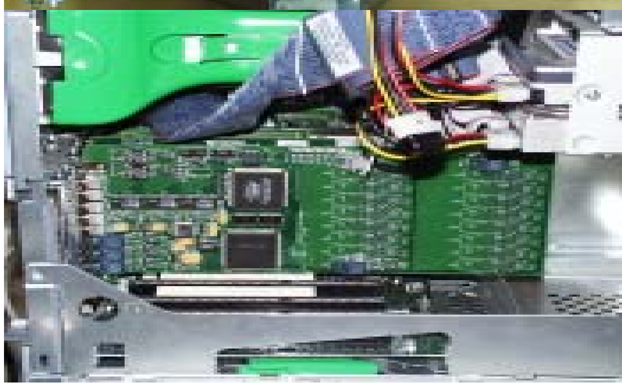
Digital feedback electronics

Digital feedback card (one per column)



3U rack controls 16 columns





PCI Card

Computer

Digital FB working

MUXing SQUIDs up to 1.6 MSa/sec

Much faster chips available

Room-Temperature Electronics

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TDM Instruments

NIST x-ray microanalysis array

1000-pixel array of TES x-ray microcalorimeters. To be used for microanalysis on an SEM.

SAFIRE

12x24 array of submillimeter bolometers in an imaging Fabry Perot. For SOFIA. Array development by NASA/GSFC IR astrophysics branch & NIST.

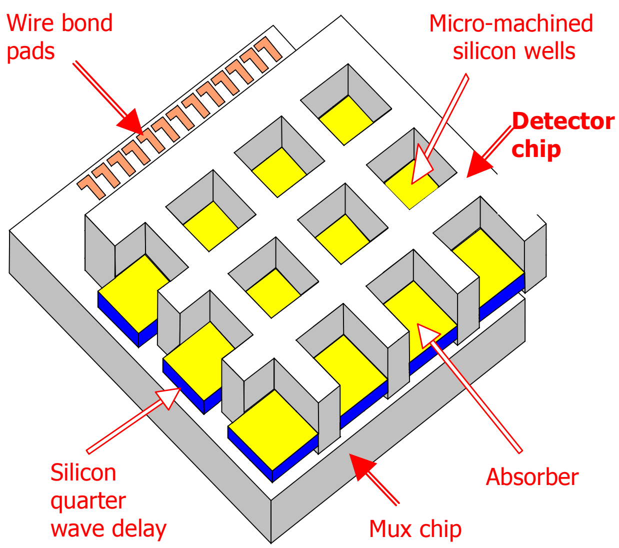
SCUBA-2

>10,000-pixel submillimeter bolometer array to be deployed at the 15 m JCMT in ~ 2006. Array development by Astronomy Technology Centre in Edinburgh and NIST.

Constellation-X (primary option; not yet downselected)

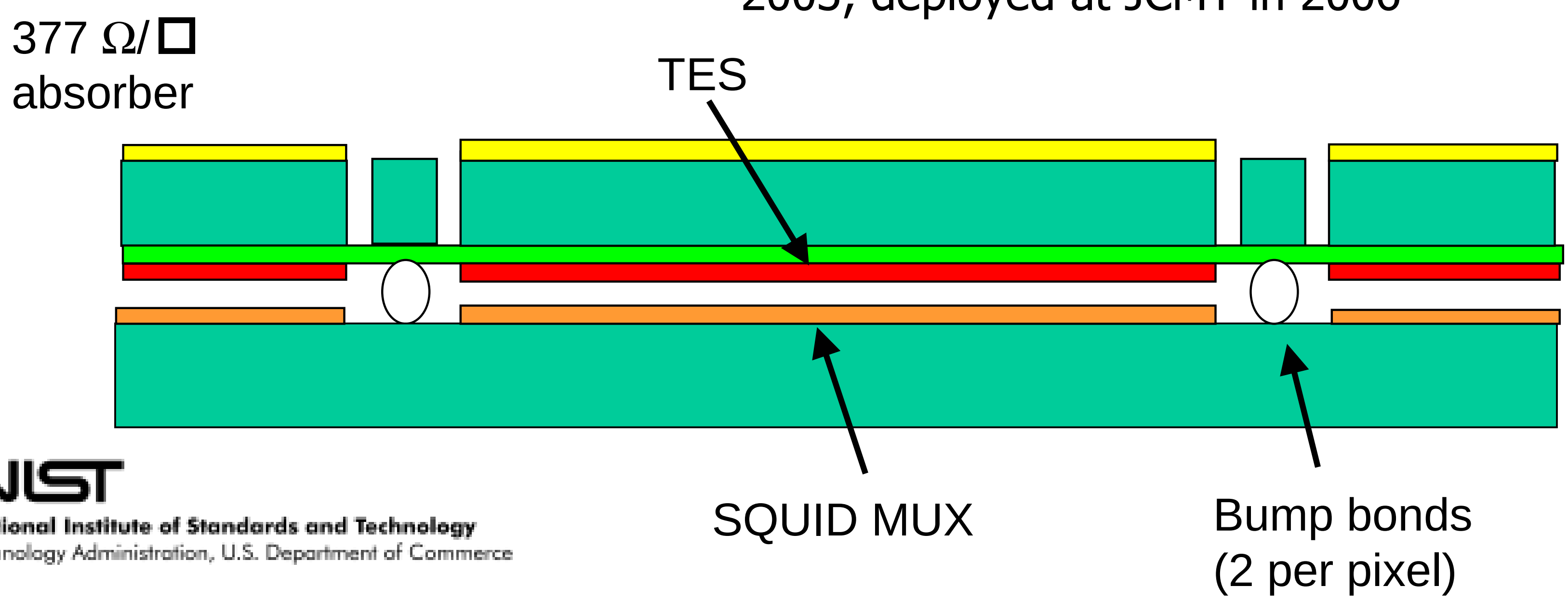
Four 1000-pixel arrays of multiplexed microcalorimeters would be flown on separate satellites. First launch scheduled for ~ 2008. Array development by NASA/GSFC x-ray calorimeter group and NIST.

SCUBA-2: 10,240-pixel in-focal-plane MUX

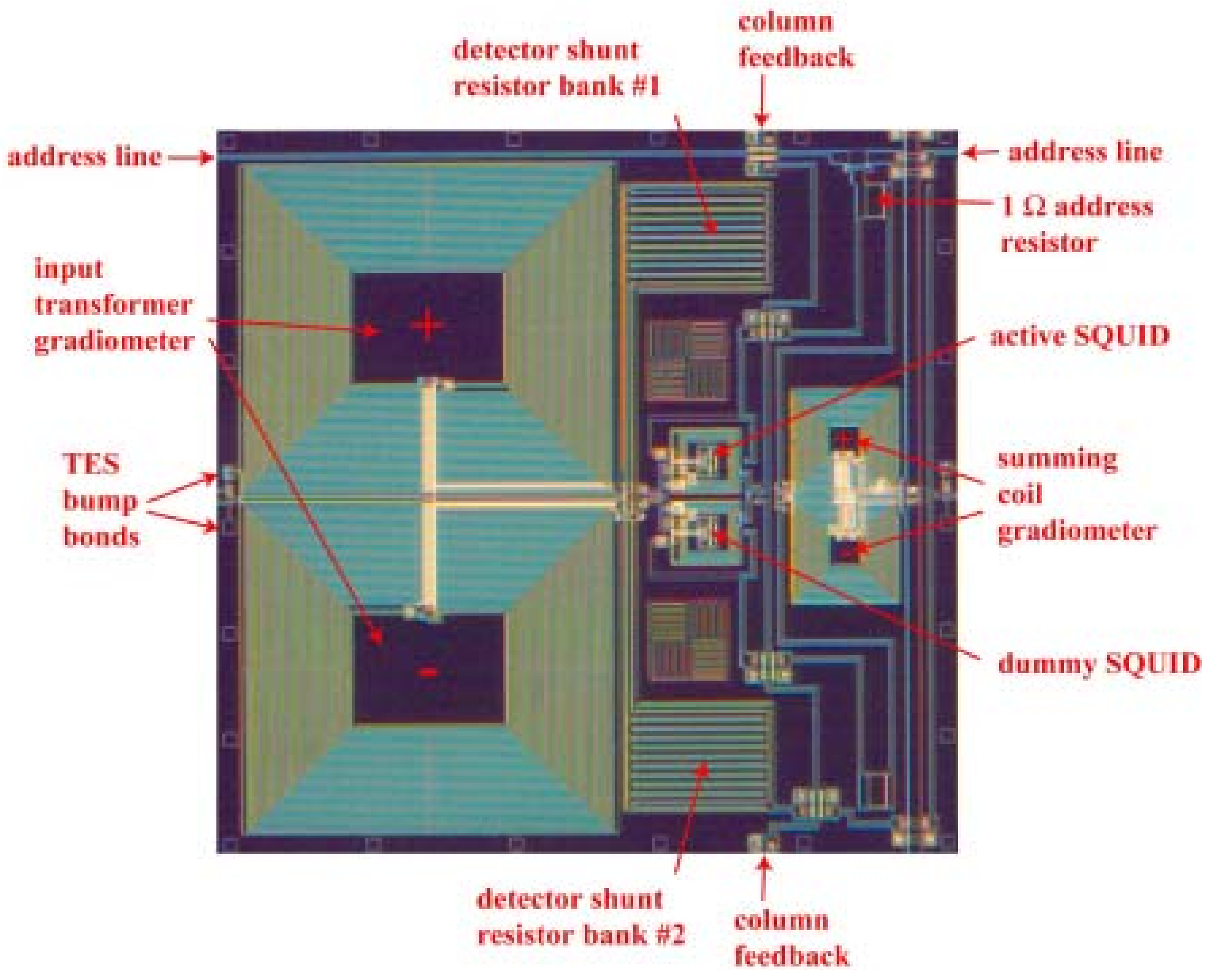


Similar to CEA Saclay architecture.

- Collaboration of the UK ATC, many institutions in the UK and Canada, NIST, and Raytheon.
- 5,120 pixels at 450 μm and 5,120 pixels at 850 μm
- First full 32 $\times$ 40 subarray will be tested in late 2003, deployed at JCMT in 2006



SCUBA-2 MUX Pixel



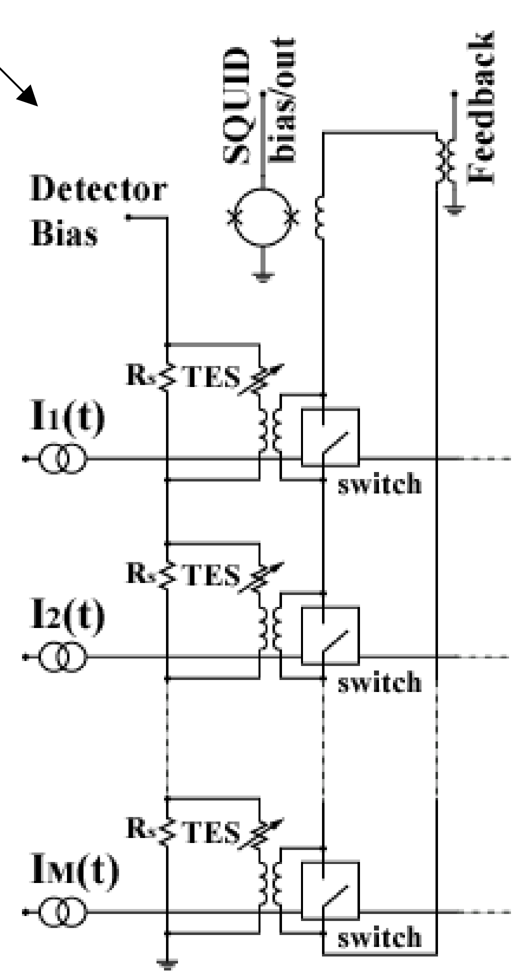
→ The MUX will degrade the noise of the SCUBA-2 850 μm array by 1.6% (due to aliased amplifier and detector noise).

Alternative switches

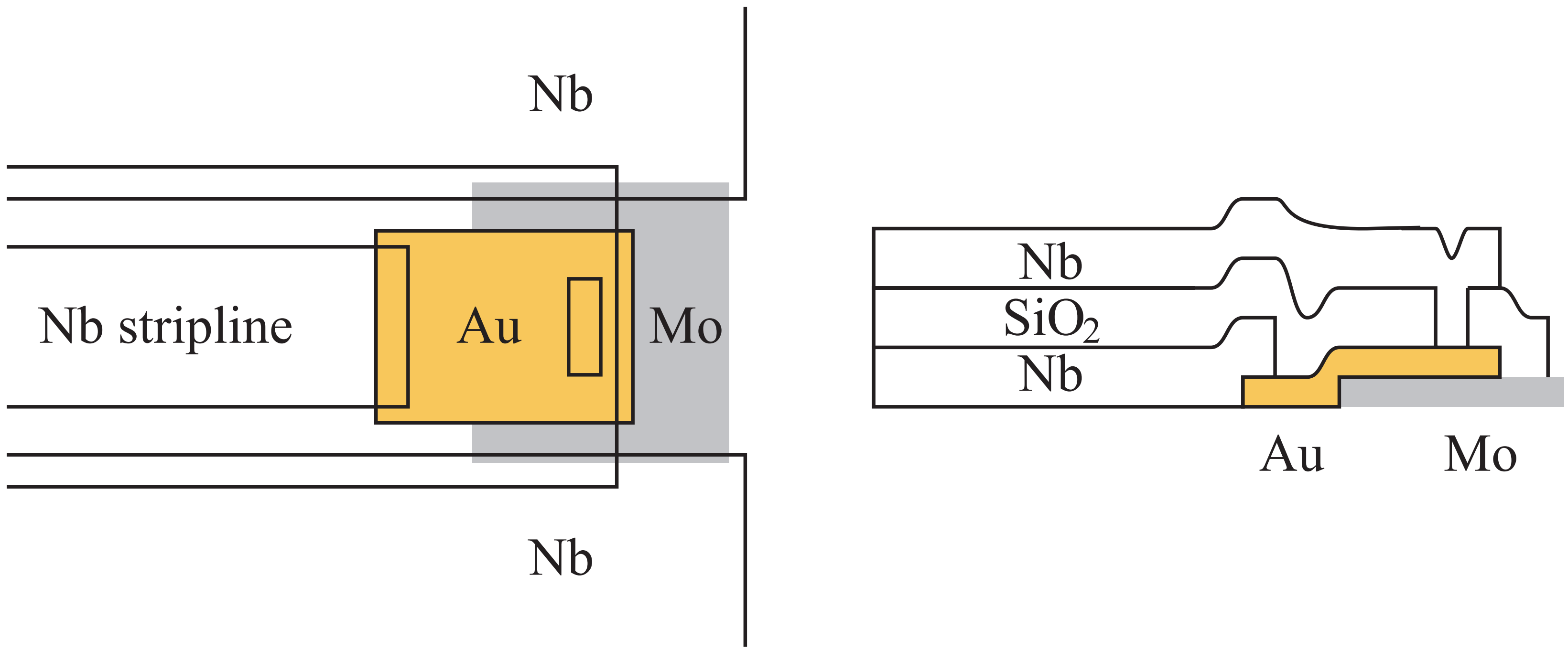
For TDM, we need high-speed, low-power, low-impedance switches

- SQUID switches
- MEMS switches
- Flux switches
- *Thermal switches*

One SQUID per column



Hot-Electron Switch



When address current flows through the normal-metal, hot electrons diffuse into the superconductor, driving it normal. When the heat is turned off, they escape into the phonon system.

Hot-Electron Switch

- Simple, small, linear, and low power.
- HEBs operate at >> 1 GHz
- We estimate that with simple, high-yield optical lithography, HESs might be made with ~ 20 MHz bandwidth and < 1 nW power dissipation.

SQUID MUX above 2 K

SQUIDs work well at 4 K, should work up to some distance below the 9 K Nb transition.

Noise goes up but still more than enough margin (0.15 $\mu\Phi_0$/rt(Hz) at 0.1 K $\mu\Phi_0$/rt(Hz) at 4 K.)

Hot-electron switches based on Nb instead of Mo should work up to ~ 9 K.

FDM filters based on superconducting coils work below Nb transition.

SQUID MUX above 9 K

High-T_c SQUIDs are available, but they are not simple integrated circuits.

For TDM, you need switches and fairly small filters. SQUID switches are possible *but require a high Tc SQUID for every pixel*. Other switches (MEMS switches, heat switches, flux switches) require considerable development.

For FDM, you need large filters at each pixel (L~40 μH, C~ 1 nF) with high-Tc superconducting coils, or very high-frequency operation and slew rates.

Lots of development required

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